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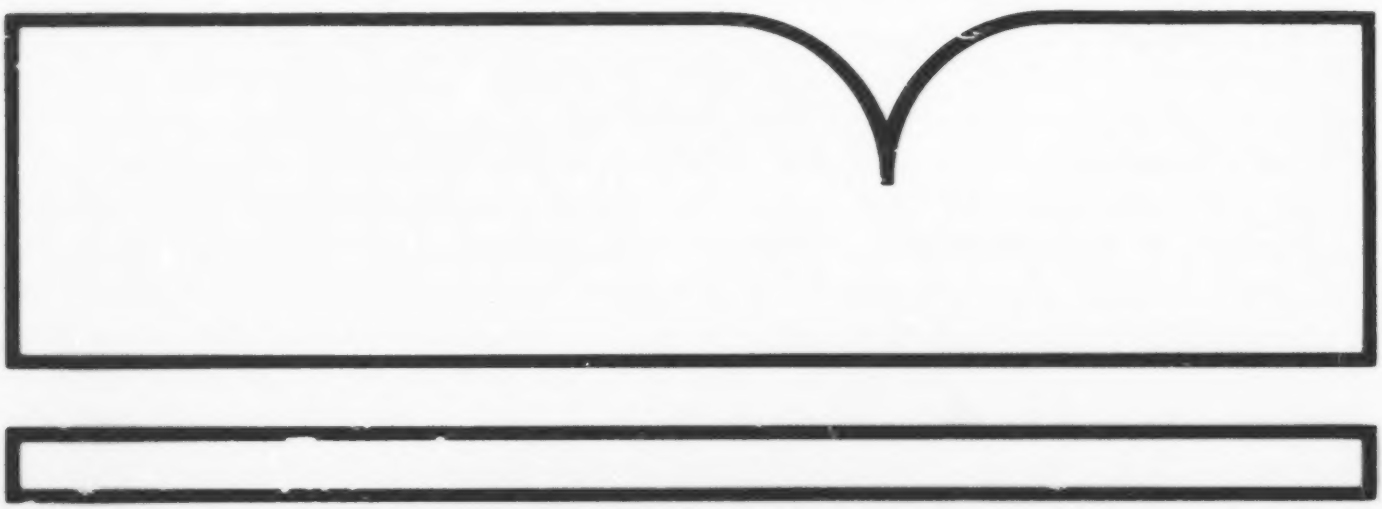

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16. ABSTRACT

This chapter describes the U.S. Environmental Protection Agency's (EPA's) monitoring project to assess the effects of changes in acidic deposition on surface waters of the United States. This project is referred to as TIME (Temporally Integrated Monitoring of Ecosystems). The TIME Project has been in the conceptual and design stage during the period 1987-1989. This planning period has allowed careful attention to many aspects of network design not usually covered prior to field implementation. The network design issues discussed in this paper are addressed within the context of the need for a policy-relevant, cost-effective national monitoring network to assess the effects of changes in atmospheric deposition of specific pollutants (sulfate and nitrate) on specific and well-defined target resources (U.S. surface waters of low acid-neutralizing capacity (ANC)).

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The TIME Project: A Case Study

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Introduction

This paper describes the U.S. Environmental Protection Agency's (EPA's) monitoring project to assess the effects of changes in acidic deposition on surface waters of the United States. This project is referred to as TIME (Temporally Integrated Monitoring of Ecosystems). The TIME Project has been in the conceptual and design stage during the period 1987-1989. This planning period has allowed careful attention to many aspects of network design not usually covered prior to field implementation. The network design issues discussed in this paper are addressed within the context of the need for a policy-relevant, cost-effective national monitoring network to assess the effects of changes in atmospheric deposition of specific pollutants (sulfate and nitrate) on specific and well-defined target resources (U.S. surface waters of low acid-neutralizing capacity (ANC)).

Although the TIME Project was originally intended as a stand-alone monitoring program as part of EPA's activities under the National Acid Precipitation Assessment Program, it was incorporated in 1989 into the larger Environmental Monitoring and Assessment Program (EMAP) being planned by EPA. EMAP is designed to assess and periodically document the condition of all ecological resources (e.g., forests, wetlands, surface waters) of the United States (EPA 1990). TIME, on the other hand, has been designed to assess the effects of changes in loadings of one particular pollutant type on one subset of a single resource type. These complementary activities can both be achieved within the EMAP structure, and many of the planning activities that have gone into TIME network design now contribute to EMAP-Surface Waters design.

In this case study, we first discuss the 1987-1989 planning goals of the TIME project. We then describe previous EPA projects relating to aquatic effects of acidic deposition upon which the TIME design is based. In the third section we describe a conceptual model for TIME that has helped focus planning activities. The last section describes the purpose and elements of TIME's Data Analysis Plan, which will now become part of EMAP-Surface Water's Data Analysis Plan. This paper updates information recently published in a closely related paper (Pollack and Ford 1989) on the same subject, and the information given here should be regarded as more current than that previous description.

TIME: Background and Project Goals

Oxidation products of atmospheric emissions of sulfur and nitrogen oxides constitute the main components of acid rain. Anthropogenic emissions of one of these components, sulfur dioxide, have been declining since the early 1970's in the northeastern United States (Husar, 1986). However, little evidence is available to suggest that the rate of lake and stream acidification in these areas has changed (Driscoll et al., 1989; Schindler, 1988). Indeed, although sulfur emissions have declined, nitrogen oxide emissions and deposition have increased, and some studies indicate that the net result may have been little change in total rainfall acidity (e.g., Hedin et al., 1987).

Recent proposals for reducing acidic deposition have targeted sulfur dioxide emissions and call for reductions of 5 million tons by 1995 and for an additional 5 million tons (plus 2 million tons of nitrogen oxide emissions) by the year 2000. These reductions will leave sulfur dioxide emissions at approximately 60 percent of current emissions. To achieve this level of control, the proposed reductions require funding commitments of approximately $700 million per year by 1995 and $3.8 billion per year by 2000. Given the magnitude of this investment, it is appropriate that a well-designed long-term monitoring program be in place to assess the effectiveness of this decrease in emissions on aquatic resources currently affected and at risk of further degradation.

The 1987-1989 planning goals of the TIME project have been to:

- provide early-warning signals of surface water acidification (or recovery) in regions of interest,

- provide an ongoing assessment of regional patterns or trends in surface water acidification (or recovery),

- assess the relationships between observed patterns and trends in surface water quality and observed patterns and trends in atmospheric deposition, and

- assess the extent to which observed patterns and trends in surface water chemistry correspond with model forecasts of surface water chemistry.

TIME has been designed to collect long-term data on acid-sensitive lakes and streams in areas of the United States considered potentially susceptible to the effects of acidic

deposition (Thornton et al., 1987; Payne and Ford, 1988). The project is designed to use information on wet deposition available through existing monitoring networks that may be augmented to meet project goals. As of March 1990, the project was scheduled for implementation in 1991.

Related EPA Studies on the Aquatic Effects of Acidic Deposition

The TIME project focuses on regions of the United States where there are lakes and streams with low levels of acid neutralizing capacity (ANC). These sensitive regions have been identified and studied in two types of major projects now underway or recently completed by EPA's Aquatic Effects Research Program (AERP). The first type includes large-scale surveys designed to identify the status and extent of surface water acidification in the United States. The second focuses on more detailed characterization and process-oriented research on selected systems, in an effort to provide an understanding of the underlying mechanisms responsible for the regionally observed patterns and effects. We briefly describe here those surveys and projects most closely related to the TIME project design.

The regional studies are collectively known as the National Surface Water Survey (NSWS). The NSWS consists of two main components, the National Lake Survey (NLS) and the National Stream Survey (NSS). The NLS in turn consists of two major regional surveys, the Eastern Lake Survey (ELS; Linthurst et al., 1986 and Landers et al., 1988) and the Western Lake Survey (WLS; Landers et al., 1987 and Eilers et al., 1988). The purpose of these regional synoptic surveys, all of which have now been completed, was to provide a snapshot characterization of the populations of interest. The regions surveyed in each of these projects are shown in Figure 1.

The Eastern Lake Survey was conducted in two phases. In Phase I, 1798 lakes were sampled once during the fall turnover period in 1984 in the Northeast, Upper Midwest, and Southeast. Phase II of the survey was conducted in 1986; 145 of the lakes sampled in the Northeast in Phase I were sampled once in each of the spring, summer, and fall seasons. During the Western Lake Survey, 719 lakes in the mountainous areas of the western United States were sampled during fall turnover in 1985. The WLS was recently augmented by the Kenai Lakes Investigation Project (KLIP), during which 59 lakes on the Kenai Peninsula of Alaska were sampled during August 1988 (Ford et al., 1988; Landers et al., 1989).

The NSS also was conducted in two phases. In the first, pilot, phase 54 stream reaches were sampled in the spring and summer of 1985 in the Southern Blue Ridge to assess the logistic and scientific feasibility of a full-scale survey (Messer et al., 1986; 1988). The full survey was then conducted in the Mid-Atlantic and Southeast in the spring of 1986, when upstream and downstream reach ends were sampled at 445 stream reaches (Kaufmann et al., 1988).

The NSWS surveys were designed to be statistically representative subsets of the population of resources at risk. For the NLS, the lake population was divided into strata defined on the basis of region, subregion, and preliminary versions of mapped alkalinity class (Omernik and Powers, 1983; Omernik and Kinney, 1985; Omernik and Griffith, 1986a, 1986b), and a probability sample of lakes (specifically, a systematically sampled list frame of lakes with a random start) was drawn within each stratum. The NSS also was stratified by region and subregion, but because listing the extensive number of streams was not feasible, a two-stage sampling scheme based on a point frame within strata was employed. Thus, in both the NLS and the NSS, systems were selected for sampling within subregions with known, but unequal, probabilities (Blick et al., 1987). This design allowed for determination of the percentage (by number and area), location, and chemical characteristics of surface water populations in potentially sensitive regions and subregions. The probability sampling approach also provides both context and rationale for selecting lakes and streams for longer term monitoring for acidic deposition effects.

One of the objectives of the NSWS was to determine the proportion of lakes or streams having a certain chemical value less than or equal to a specified value. Such a proportion is easily estimated as the ratio of the estimated number of lakes (or streams) that meets that criterion divided by the estimated number of lakes (or streams) in the population of interest. This ratio can be calculated for the whole range of criteria encompassed by the data, and can be plotted as a relative cumulative frequency distribution function (Sanders et al. 1983); curves can then be overlain to compare characteristics of regional or subregional populations. Figures 2a and 2b are examples of these curves for ANC in lakes in all NLS regions and in WLS subregions, respectively. Median ANC values can be compared by extending a horizontal line from 0.5 on the ordinate; thus in Figure 2a we see that median ANC is lowest in Florida (about 75 μeq/L) and highest in the Upper Midwest (about 350 μeq/L). The proportion of lakes with ANC less than 200 μeq/L can be compared by extending a vertical line from 200 on the abscissa; in Figure 2b, for example, we see that about 85

percent of the lakes in the California subregion and about 40 percent of the lakes in the Southern Rockies subregion have ANC values below this critical level.

The Direct/Delayed Response Project (DDRP) (Church 1989) was implemented after NSWS sampling and was intended to provide an understanding of the underlying mechanisms responsible for the observed patterns in surface water chemistry. Under DDRP, regional soil surveys were made on statistically representative sets of watersheds consistent with the NSWS, and three models of surface water acidification or recovery (MAGIC, ILWAS, and Enhanced Trickle-Down) were applied in order to predict changes in surface water chemistry likely to occur under various sulfate deposition scenarios (Jenne et al., 1989). In principle, the DDRP could set the primary context for assessment activities related to determining whether patterns and trends in surface water chemistry observed in the TIME network following emissions reductions correspond with DDRP model forecasts for surface water effects. In reality, this task is complicated by the fact that, in order for these comparisons to be valid, emission reductions scenarios would have to exactly match the assumed scenarios actually used in DDRP, which is unlikely to be the case.

The Long Term Monitoring (LTM) project was initiated in 1982 to follow trends in surface water chemistry of systems with low ANC across national and regional gradients of atmospheric sulfate deposition (Newell et al., 1987; Ford et al., in review). This is a cooperative project, in that EPA has supported federal, state, and university researchers in chemical monitoring of 90 lakes and streams. These surface water systems are located across the northeastern and northcentral United States as far west as Colorado (Figure 3), and are typically sampled monthly or seasonally. More complete descriptions of the LTM project may be found in Newell et al. (1987) and Ford et al. (in preparation).

Conceptual model of the TIME Project

A working conceptual model for the TIME project used during the 1987-1989 planning period is depicted in Figure 4. The left side of the figure represents the existing NSWS program elements upon which the TIME project has been built; the axle represents the temporally intensive LTM project and the wheel is a collective representation of the statistically representative regional surveys. The right side of the figure extends this analogy to the TIME project.

The wheels are designed to provide periodic assessments of status and trends for particular geographic regions and surface water subpopulations of interest. Axle systems will be chosen to represent particular subpopulations of interest, and will provide additional information on seasonal and annual variability necessary to interpret information derived from the regional assessments. For axle systems that are not elements of the NSWS (referred to as "found" sites), the relationship between these sites and sites in the NSWS population will be described using appropriate statistical approaches (e.g., Overton, 1989; Ford et al. 1990 and in review). Combining temporally intensive and regionally extensive elements in the TIME design balances the need for regional assessments with the need for ongoing monitoring of rapid response systems for networks addressing specific pollutant impacts such as acidic deposition.

Periodic regional assessments can occur on any sampling schedule, and can easily be developed within the EMAP context as either resurveys of subsets of NSWS sites or resurveys of EMAP sites at grid densities appropriate to the TIME objectives. One possible sampling scheme for the eastern U.S., for example, would be to focus sampling on the DDRP sites in the Northwest, Mid-Atlantic, and Southern Blue Ridge Province, since the DDRP sites are themselves a subset of NSWS sites. Regional assessments can follow the original NSWS protocol, with a single sampling effort during an "index" period of relatively stable water chemistry (e.g., fall turnover for lakes, spring baseflow for streams). Other possibilities for articulating complementary temporally intensive and regionally extensive elements of project design will undoubtedly arise as the EMAP planning and design process continues.

The TIME Data Analysis Plan

The outline for TIME's Data Analysis Plan (DAP) began in late 1987 and the process to date in working through the elements of the DAP has been valuable in identifying issues that guide monitoring network design. The activities identified in TIME's DAP are currently expected to contribute to the overall Data Analysis Plan for EMAP-Surface Waters. In this section, we discuss the original elements of TIME's DAP to elucidate the types of planning activities that have thus far influenced the design of the TIME water quality information system.

The purpose of the Data Analysis Plan is to describe the statistical analyses that will be

performed to address the major monitoring questions and policy issues of interest. By initiating the DAP activities well in advance of actual field implementation, the information needs of prospective methods of data analysis can be incorporated into the actual design of the monitoring network. The kinds of decisions that could be influenced by these activities include the number and geographic distribution of surface water and deposition sites, the frequency and amount of replication of sampling efforts, and the number and types of quality control samples.

The TIME DAP technical chapters and the primary issues identified for each are as follows:

- Trends in individual surface water systems. How do we assess whether or not there are meaningful statistically significant changes over time in a specific response variable for an individual system? In a vector of variables? Are there advantages to using multivariate, rather than univariate, trend detection techniques?

- Trends in regional populations. How do we characterize given response variables for populations of interest in a region or subregion? How do we compare the distribution of a response variable between two time periods? How can univariate and multivariate trends in regional populations of surface water systems be estimated, and how do we assess whether observed trends in response variables are both statistically significant and ecologically meaningful?

- Trends in biological parameters. What kinds of information can biological response variables add to a chemical monitoring program? What biological response variables should be used to assess aquatic effects of acidic deposition? Which response variables are best for early-warning signals, which are best for regional assessment of change from one time period to another, and which are best for detecting biological trends over time? How do we assess, at any given point in time, whether or not these biological response variables have gone below or exceeded a critical level? What statistical techniques are appropriate for the assessment of changes over time in the biological response variables of interest?

- Integration of non-NSWS surface water systems into NSWS populations. How do we determine the subsets in the probability sample that are represented by the individual (axle) surface water systems? To what extent can we extrapolate

observed changes in individual surface water systems to changes in subpopulations in given regions or subregions? To what extent can we use observed variability in trends in individual systems or groups of axle systems to estimate variability in the subpopulation trends?

- Trends in deposition. Is it necessary to co-locate deposition and surface water monitoring sites? Can deposition to axle systems be adequately represented by data from existing deposition monitoring sites? How representative are the regional deposition networks of the TIME regional populations? Is it necessary to estimate and test the statistical and practical significance of trends in deposition at individual stations, and if so what are the best techniques to do so? How do we estimate and test the statistical and practical significance of regional deposition trends?

- Relationship between trends in deposition and trends in surface water chemistry. How do we assess whether or not there are statistically and practically significant relationships between changes in deposition and changes in surface water chemistry in an individual surface water system? Between changes in deposition and changes in regional surface water chemistry?

The technical chapters in the Data Analysis Plan are intended to describe and provide sample applications of the approaches recommended for data analysis by cooperating researchers, as well as descriptions of other approaches considered and justifications for the selection of specifically recommended approaches. The assumptions and the sensitivity of analytical results to these assumptions also will be described.

The Data Analysis Plan is intended to be read by a wide audience; thus the recommended techniques will be explained at a level understandable by scientists and decision-makers with a knowledge of basic statistics. Appendices to the document will describe the recommended techniques in greater technical detail for these who are interested. In particular, the Appendices are intended to be sufficiently detailed so that data analysts, database managers, and programmers can use them as guides to implementation of recommended techniques.

More detailed descriptions of TIME's design and discussion of the scientific issues underlying the issues targeted in the Data Analysis Plan can be found in several recent and

forthcoming publications. Project history and design are discussed in Ford (in review). Young and Ford (1989) describe a process by which the NSWS data base can be analyzed to optimize site selection for both the early-warning and the regional assessment components of the TIME design. Young (submitted) gives a detailed description of a chemical model for evaluating potential sites of interest using this process, and Ford et al. (1990 and in review) give applications of this model to data from LTM sites. Overton (1989 and in review) describes a means of relating non-NSWS sites to the NSWS probability sample.

Selection of appropriate statistical techniques for univariate trend detection were studied using a large scale Monte Carlo simulation experiment (Taylor and Loftis 1989) The implications of these results for the TIME project are discussed by Loftis and Taylor (1989) and Ford (in review). These analyses are currently being extended to consider multivariate trend detection techniques. A related issue explored in connection with these analyses was determining the time to detection of statistically significant trends (given realistic trend magnitudes) at given level of Types I and II errors, given various combinations of site density and monitoring frequency (Loftis and Taylor 1989). The critical issue in these analyses related to the likelihood of obtaining usable trend information in policy-relevant time frames. Good variance estimates for the chemical response variables of interest were necessary for these kinds of analyses, as were estimates of likely trend magnitudes. In the case of the TIME Project, the former type of information was in fact available by virtue of the combined existence of information from both the NSWS and the LTM Project. The latter type of information, likely trend magnitudes, was bounded by examining DDRP predictions as well as records from a Sudbury lake current experiencing rapid chemical amelioration due to large local decreases in deposition from the Sudbury plants (Dillon, pers. comm.).

Identifying statistical techniques for regional trend detection is a complex task. Preliminary progress was made in this arena in the analysis of the ELS Phase II data (Overton, 1988), in which regional data from four different time periods was available for analysis (spring, summer and autumn of 1986 and, from Phase I, autumn of 1984). Continued development of this area is underway within the context of EMAP (Stevens, pers. comm.)

Hughes (1989) gives an overview of the rationale for biological monitoring, and the usefulness of various specific biological response variables for the particular purposes of the TIME project was considered at the U.S.-Canadian Workshop on Biological Monitoring for Acidification Effects, summarized by Marmorek et al. (1988). Publication of this latter

document together with revisions of the eight background papers prepared for the workshop by North American experts in five different organismal groups is in progress (phytoplankton (diatoms, chrysophytes, green and blue-green algae, and dinoflagellates), periphyton, zooplankton, benthic invertebrates, and fish).

Deposition has received relatively less attention, although recently Daly (1989) has outlined a preliminary conceptual approach for estimating wet deposition to TIME regions and individual monitoring sites, and for assessing the adequacy of existing deposition monitoring networks for representing deposition to regions of concern for TIME. Further elaboration of the deposition network design will be undertaken in the context of EMAP-Air/Deposition.

Summary

The design of a national monitoring network to assess the effects of changes in acidic deposition on surface waters of the U.S. is a complex undertaking. EPA's approach has been to embed this design in the context of ten years of NAPAP-related research. Outlining the elements of a Date Analysis Plan for this network helped in the early identification of issues that affect network design, and have allowed technical studies to be undertaken to address pertinent issues. We briefly discuss several kinds of analyses that will be used to guide network design decisions of issues such as geographic coverage, site density and selection, monitoring frequency, appropriate response variables, frequency and amount of replication in sampling efforts, and numbers and types of quality control samples.

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REFERENCES

Barchet, W.R. 1987. Acidic deposition and its gaseous precursors. in Chapter 5, NAPAP Interim Assessment: The Causes and Effects of Acidic Deposition. Vol. III: Atmospheric Processes and Deposition. U.S. Government Printing Office, Washington, D.C.

Blick, J., J.J. Messer, D.H. Landers, and W.S. Overton. 1987. Statistical basis for the design and interpretation of the National Surface Water Survey, Phase I: lakes and streams. Lake Reserv. Manage. **3**:470-475.

Church, M.R. 1989. Direct/Delayed Response Project: Predicting future long-term effects of acidic deposition on surface water chemistry. EOS **70**:801-813

Daly, C. 1989. Estimation of wet deposition to surface water systems for the TIME Project: A geographic approach. pp. 436-446 in R.C. Ward, J.C. Loftis, and G.B. McBride (editors). Proceedings International Symposium on the Design of Water Quality Information Systems. Information Series No. 61. Colorado Water Resources Research Institute. Colorado State University, Fort Collins, Co.

Driscoll, C.T., G.E. Likens, L.O. Hedin, J.S. Eaton, and F.H. Bormann. 1989. Changes in the chemistry of surface waters. Environ. Sci. Technol. **23**(2):137-143.

Eilers, J. M., D. F. Brakke, D. H. Landers, and P. E. Kellar. 1988. Characteristics of lakes in mountainous areas of the western United States. Verh. Internat. Verein. Limnol. **23**:144-151.

EPA 1990. Environmental Monitoring and Assessment Program. Overview. EPA/600/9-90/001. U.S. Environmental Protection Agency Office of Modeling, Monitoring Systems, and Quality Assurance (RD-680). Washington, D.C.

Ford, J. In review. The evolution of a policy-relevant monitoring network: EPA's TIME Project.

Ford, J., A.D. Newell, T.C. Young, P.L. Brezonik, C.T. Driscoll, J.S. Kahl, and K.E. Webster. In review. Long-term monitoring for surface water response to acidic deposition: inferences from the U.S. EPA's LTM Project.

Ford, J., T. Young, and J. Stoddard. 1990. Long-term monitoring for aquatic effects of acidic deposition: An approach to regionalizing information from existing monitoring sites. Proceedings of the Workshop on Assessment and Monitoimg of Acidification of Rivers and Lakes, Freiburg, FRG. 17-19 October 1989.

Ford, J., D. Landers, and J. Eilers. 1988. "Kenai Lakes Investigation Project (KLIP): Acid Rain Research in Alaska." Ann. Mtng. Am. Assn. Adv. Sci. - Arctic Div. Fairbanks, AK, October 1988.

Hedin, L.O., G.E. Likens, and F.H. Bormann. 1987. Decrease in precipitation acidity resulting from decreased SO_4 concentration. Nature **325**:244-246.

Hughes, R.M. 1989. What can biological monitoring tell us about environmental health? pp. 447-460 in R.C. Ward, J.C. Loftis, and G.B. McBride (editors). Proceedings International Symposium on the Design of Water Quality Information Systems.

89084

Information Series No. 61. Colorado Water Resources Research Institute. Colorado State University, Fort Collins, Co.

Husar, R.B. 1986. Emissions of sulfur dioxide and nitrogen oxides and trends for eastern North America. In: Acid Deposition: Long-Term Trends (pp. 48-92). Committee on Monitoring and Assessment of Trends in Acid Deposition. National Academy Press, Washington, D.C.

Jenne, E.A., L.E. Eary, L.W. Vail, D.C. Girvin, A.M. Liebtrau, L.F. Hibler, T.B. Miley, and M.J. Monsour. 1989. "An Evaluation and Analysis of Three Dynamic Watershed Acidification Codes (MAGIC, ETD, and ILWAS)." Pacific Northwest Laboratory (PNL-6687).

Kaufmann, P. R., A. T. Herlihy, J. W. Elwood, M. W. Mitch, W. S. Overton, M. J. Sale, J. J. Messer, K. A. Cougan, D. V. Peck, K. H. Reckhow, A. J. Kinney, S. J. Christie, D. D. Brown, C. A. Hagley, and H. I. Jager. 1988. Chemical Characteristics of Streams in the Mid-Atlantic and Southeastern United States. Volume 1. Population Descriptions and Physico-Chemical Relationships. EPA/600/3-88/021a. U. S. Environmental Protection Agency, Washington, DC.

Landers, D. H., J. M. Eilers, D. F. Brakke, W. S. Overton, P. E. Kellar, M. E. Silverstein, R. D. Schonbrod, R. E. Crowe, R. A. Linthurst, J. M. Omernick, S. A. Teague, and E. P. Meier. 1987. Characteristics of Lakes in the Western United States. Volume 1. Population Descriptions and Physico-Chemical Relationships. EPA/600/3-86/054a. U. S. Environmental Protection Agency, Washington, DC.

Landers, D. H., W. S. Overton, R. A. Linthurst, D. F. Brakke. 1988. Eastern Lake Survey. Environ. Sci. Technol. **22**(2):128-135.

Landers, D. H. et al. 1989. "Regional Evaluation of Lakes on the Kenai Peninsula of Alaska." 42nd Annual meeting, American Society of Limnology and Oceanography, Fairbanks, AK, June 1989.

Linthurst, R. A., D. H. Landers, J. M. Eilers, D. F. Brakke, W. S. Overton, E. P. Meier, and R. E. Crowe. 1986. Characteristics of Lakes in the Eastern United States. Volume 1. Population Descriptions and Physico-Chemical Relationships. EPA/600/4-86/007a. U. S. Environmental Protection Agency, Washington, DC.

Loftis, J.C. and C.H. Taylor. 1989. Detecting acid precipitation impacts on lake water quality. Envionrmental Management **13**:

Loftis, J.C., R.C. Ward, R.D. Phillips, and C.H. Taylor. 1989. An evaluation of trend detection techniques for use in water quality monitoring programs. EPA/600/3-89/037. Environmental Protection Agency, Washington, D.C.

Marmorek, D.R., D.P. Bernard, and J. Ford. 1988. Biological monitoring for acidification effects: results of a U.S.-Canadian workshop. Internal report.

Messer, J. J., C. W. Ariss, J. R. Baker, S. K. Drouse, K. N. Eshelman, P. R. Kaufmann, R. A. Linthurst, J. M. Omernick, W. S. Overton, M. J. Sale, R. D. Schonbrod, S. M. Stambaugh, and J. R. Tuschall, Jr. 1986. National Stream Survey Phase I - Pilot Survey. EPA/600/4-86/026. U. S. Environmental Protection Agency, Washington, DC.

89084

Messer, J.J., C.W. Ariss, J.R. Baker, S.K. Drous , K.N. Eshleman, A.J. Kinney, W.S. Overton, M.J. Sale, and R.D. Schonbrod. 1988. Stream chemistry in the Southern Blue Ridge: feasibility of a regional synoptic sampling approach. Water Resources Bulletin 24(4):821-829.

Newell, A.D., C.F. Powers, and S.J. Christie. 1987. Analysis of Data from Long-Term Monitoring of Lakes. EPA/600/4-87/014. U.S. Environmental Protection Agency, Washington, DC.

Pollack, A.K. and J. Ford. 1990. The TIME Project: An Overview. pp. 413-424 in R.C. Ward, J.C. Loftis, and G.B. McBride (editors). Proceedings International Symposium on the Design of Water Quality Information Systems. Information Series No. 61. Colorado Water Resources Research Institute. Colorado State University, Fort Collins, Co.

Omernik, J.M., and C.F. Powers. 1983. Total alkalinity of surface waters -- a national map. Annals of the Association of American Geographers 73:133-136.

Omernik, J.M., and A.J. Kinney. 1985. Total Alkalinity of Surface Waters: A Map of the New England and New York Region. EPA/600/D-84/216. U.S. Environmental Protection Agency, Corvallis, OR.

Omernik, J.M., and G.E. Griffith. 1986a. Total alkalinity of surface waters: a map of the Upper Midwest Region of the United States. Environmental Management 10:829-839.

Omernik, J.M., and G.E. Griffith. 1986b. Total Alkalinity of Surface Waters - A Map of the Western Region. EPA/600/D-85/219. U.S. Environmental Protection Agency, Corvallis, OR.

Overton, W.S. 1988.

Overton, W.S. 1989. "On the Use of Found Sites in a Rigorous Monitoring Program." Paper presented at the International Symposium on the Design of Water Quality Information systems, Fort Collins, Co. June.

Overton, W.S. 1990. In review.

Payne, F. E. and J. Ford. 1988. "The Concept of TIME -- Temporally Integrated Monitoring of Ecosystems. Supplement." Internal report. U. S. Environmental Protection Agency Environmental Research Laboratory, Corvallis, OR.

Sanders, T.G., R.C. Ward, J.C. Loftis, T.D. Steele, D.D. Adrian, and V. Yevjevich. 1983. Design of Networks for Monitoring Water Quality. Water Resources Publications. Littleton, Co. 328 pp.

Schindler, D.W. 1988. Effects of acid rain on freshwater systems. Science 239:149-157.

Taylor, C.H. and J.C. Loftis. 1989. Testing for trend in lake and ground water quality time series. Water Resources Bulletin **25**: 715-726.

Thornton, K. W., F. E. Payne, J. Ford, and D. H. Landers. 1987. "The Concept of TIME." Internal report. U. S. Environmental Protection Agency Environmental Research

Laboratory, Corvallis, OR.

Young, T.C. Submitted. A chemical model for assessment of lake sensitivity and response to acid or base input.

Young, T.C. and Ford, J. 1989. Site selection procedures for Temporally Integrated Monitoring of Ecosystems (TIME). in R.C. Ward, J.C. Loftis, and G.B. McBride (editors). Proceedings International Symposium on the Design of Water Quality Information Systems. Information Series No. 61. Colorado Water Resources Research Institute. Colorado State University, Fort Collins, Co.

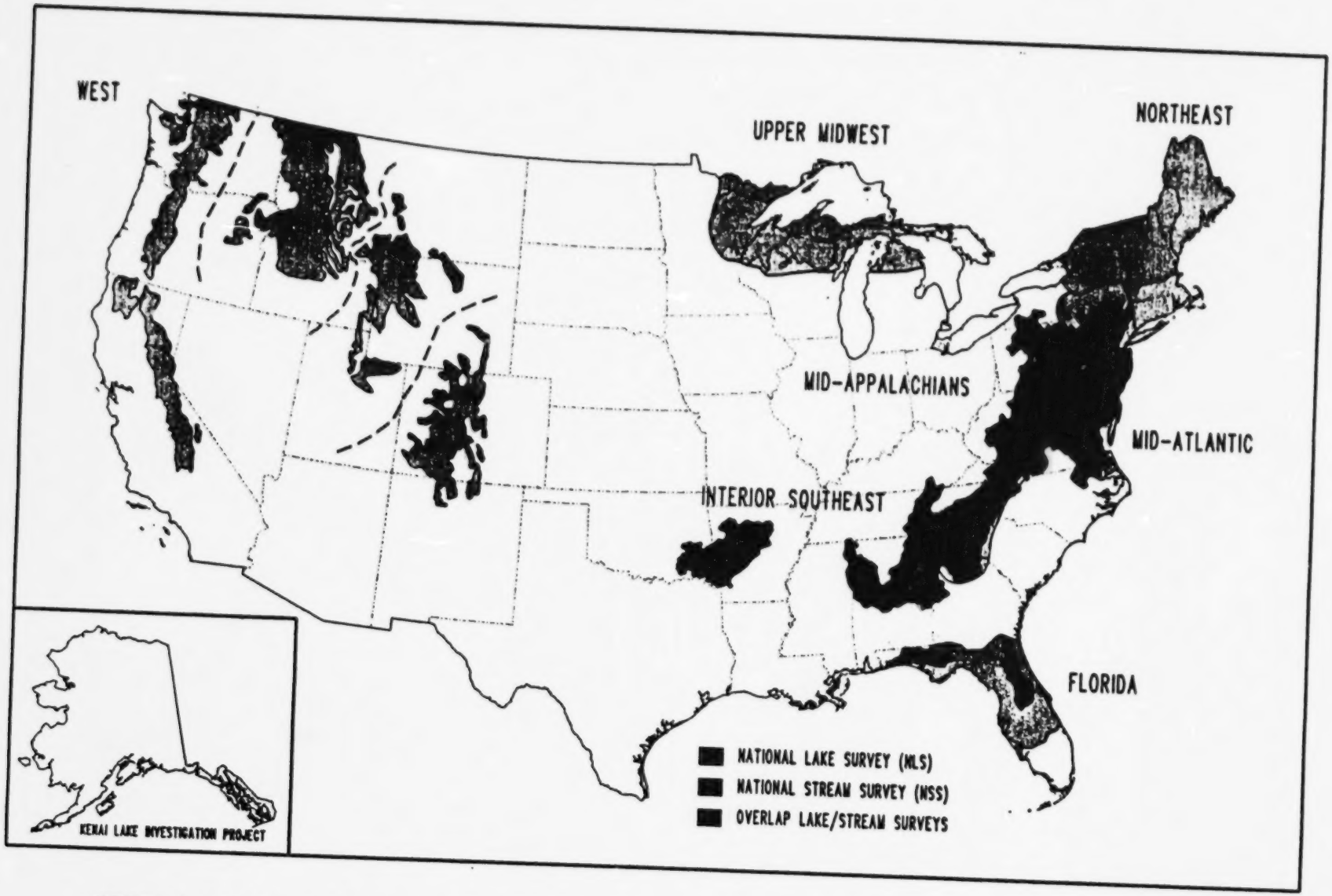

FIGURE 1. Regions of interest in the National Surface Waters Survey.

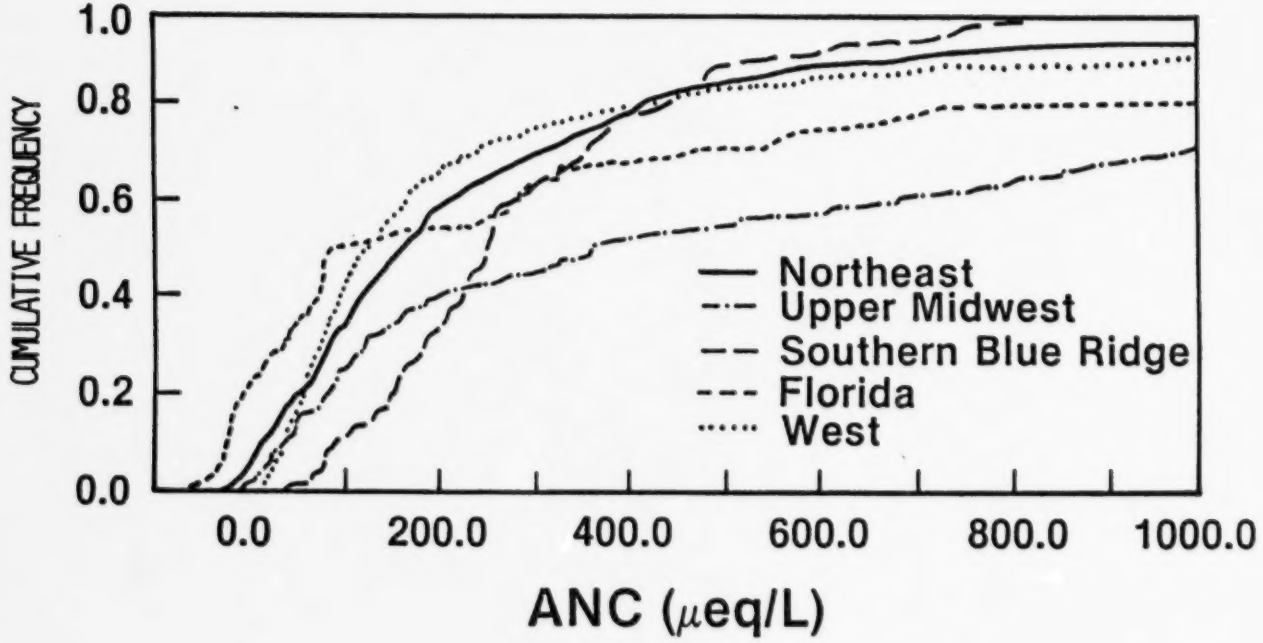

FIGURE 2a. Cumulative frequency distributions for acid neutralizing capacity in National Surface Water Survey regions.

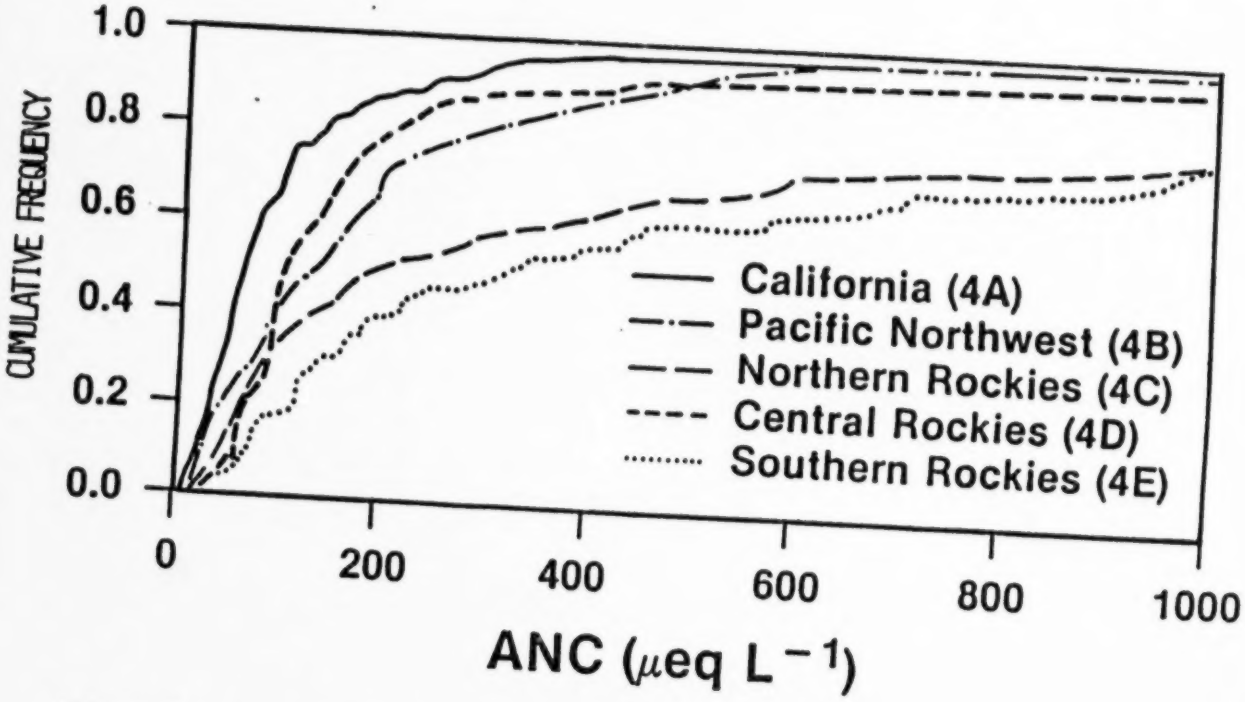

FIGURE 2b. Cumulative frequency distributions for acid neutralizing capacity in lakes in subregions of the Western Lake Survey. Source: Landers et al., 1987.

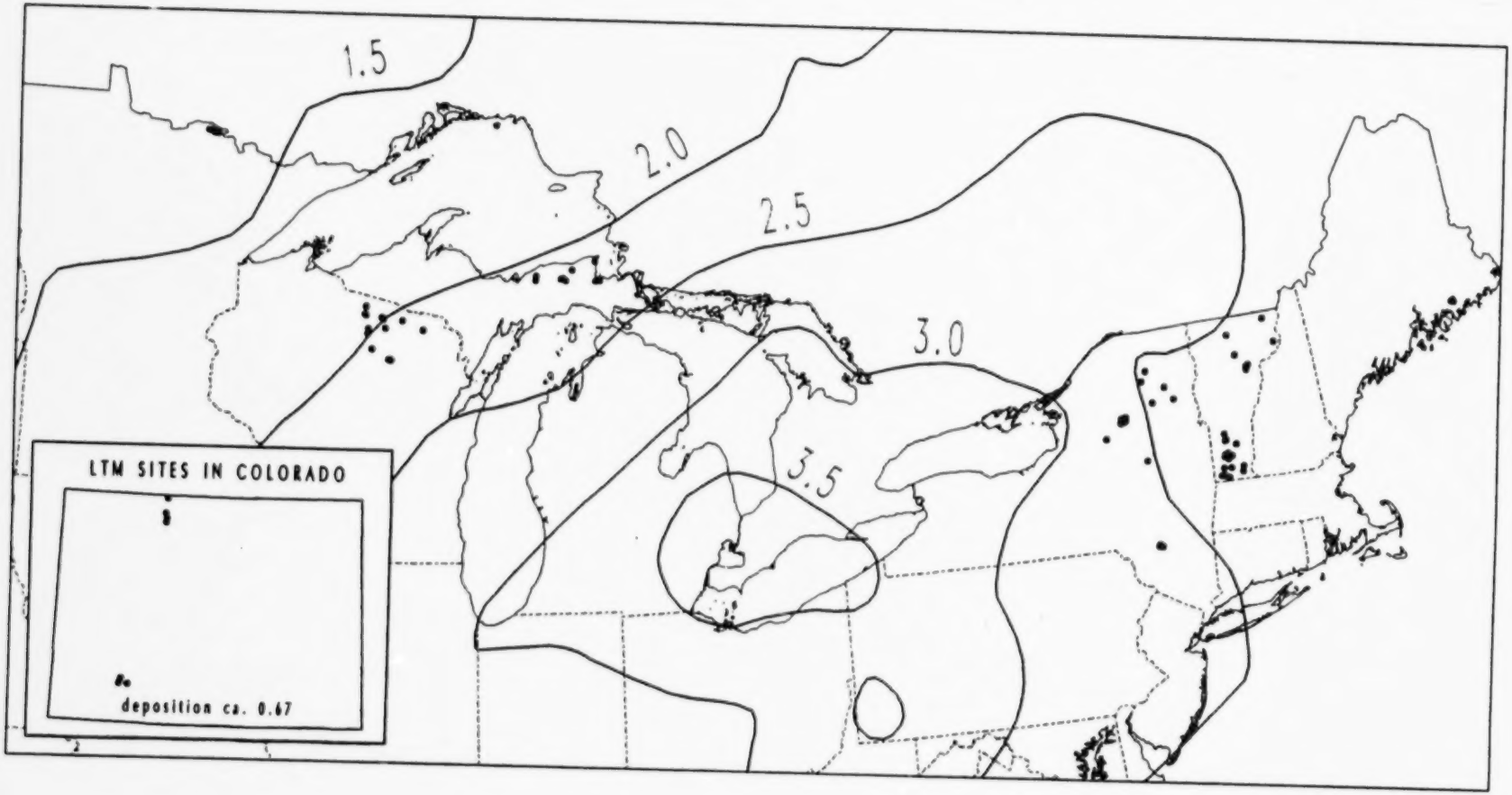

FIGURE 3. Long Term Monitoring project sites with wet sulfate deposition contours (g/m^2 per year, 1980-1984 average). Source: ~~Ford et al., 1989~~. Barchet 1987

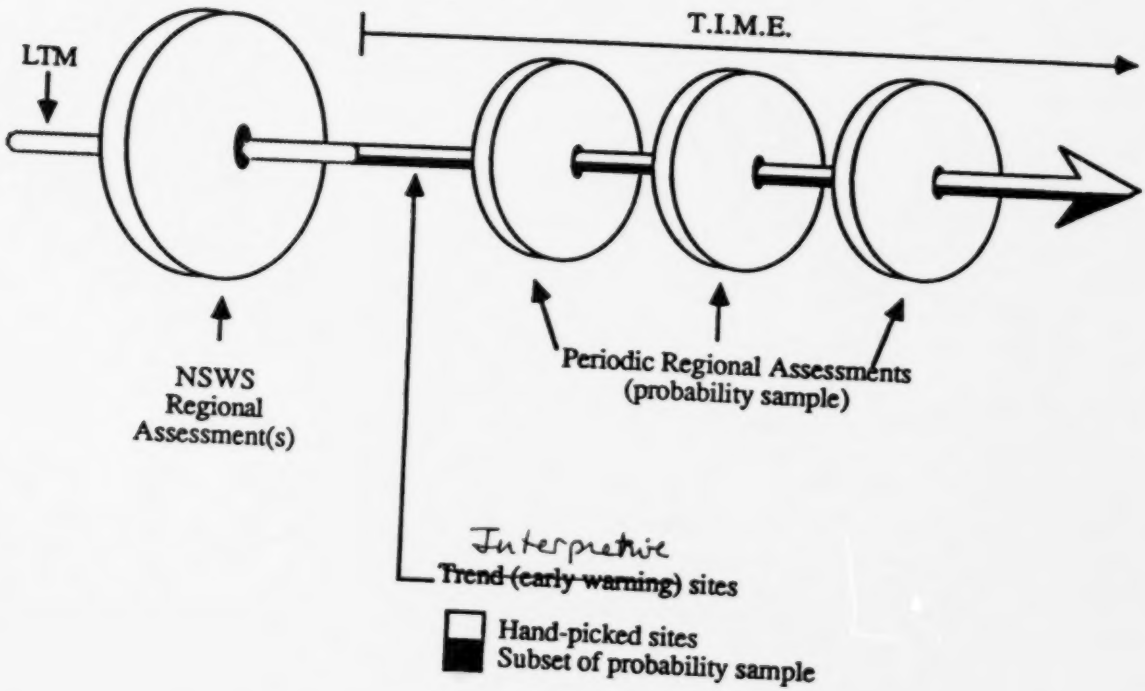

FIGURE 4. Temporally Integrated Monitoring of Ecosystems (TIME) project conceptual ~~"wheel and axle"~~ model.